



RAPID REVIEW OF ADVANCES IN MOLECULAR DIAGNOSTICS AND FORENSIC MEDICINE CHALLENGES IN HEALTHCARE: THE CONTEXT OF PRECISION MEDICINE AND ARTIFICIAL INTELLIGENCE

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Abstract

Background

Forensic medicine and healthcare are two of the fastest evolving fields, thanks to molecular diagnostics and a variety of “technologies such as next-generation sequencing”, CRISPR, and microfluidic DNA tools, which are able to improve detection of disease, evidence interpretation and molecular autopsies, while the clinical and legal contexts enjoy better speed, accuracy and data integration with the help of AI.

Method & Data

Google Scholar searches after 2024 were used to conduct a rapid review. A combination of terms linking precision care, molecular diagnostics and forensic medicine were used to identify sixty-three records and find seventy-two records. PRISMA-style process was used to capture current trends and AI applications from 63 studies pruned after checking for duplications.

Findings

Various fields such as predictive modelling, forensic biomarker analysis, automation and multi-omics data interpretation are all connected through AI. Similarly, diagnosis, degraded DNA analysis, and digital autopsy workflows were found to be improved through molecular methods. But hindrances still exist, such as high implementation costs, regulatory inconsistency, ethical problems and limited global standardization.

Future Directions

AI-enabled diagnostics, digital biobanking, “epigenetic profiling, and integration of multi-omics data for precision” and “forensic applications” are some of the main fields that would be focused on through research. But various experts including clinicians, forensic experts and data scientists should collaborate to improve accessibility, governance and translational impact.

Keywords: Molecular diagnostics, Forensic medicine, Artificial intelligence, Precision medicine, Multi-omics, Epigenetics, CRISPR, Digital biobanking

Introduction and background of the Study

Clinical care and forensic investigation find themselves completed evolving with the help of molecular diagnostics as faster and more precise biological analysis can be conducted. Detection of disorders, infections, cardiovascular problems and cancers finds itself greatly improved with the help of technologies such as next-generation sequencing, CRISPR-based assays, and AI-supported amplification tests. Tailoring treatments to cater individual patients and tracking pathogens in clinical

environments is also possible due to these technologies. But the uptake of these technologies suffers greatly from high costs, regulations and constraints, and limited infrastructure. ATAC-sequencing, microfluidic DNA platforms and third generation sequencing enhanced evidence interpretation, and molecular methods help in postmortem analysis by extracting genetic information from degraded samples, identifying biomarkers in cases of injuries or diseases and asserting molecular autopsies in unexplained deaths.

The study has provided detailed review of literature in the specific areas concerning molecular diagnostics and forensic medicine and healthcare and Molecular Diagnostics, Forensic Medicine, and Precision Medicine during the past couple of years in the beginning sections and focused on rapid review of AI applications in the later section.

Method for data collection

To conduct a comprehensive literature search on Google Scholar since 2024, a total of 72 references were found and identified by using targeted keywords and Boolean combinations as given (table 1 and 2). The primary search phrases included “molecular diagnostics and forensic medicine and healthcare” and “Molecular Diagnostics, Forensic Medicine, and Precision Medicine”, ensuring a broad yet focused retrieval of studies across all types of documents. The results were sorted by relevance to prioritize high-impact and recent contributions in the field, encompassing reviews, original research articles, and systematic analyses. This approach allowed the compilation of a robust dataset reflecting the latest advances in molecular diagnostics and their applications in forensic and precision medicine contexts.

The following aspects are significant:

- google scholar literature search
- since 2024
- sorting the results by relevance among all types of documents

Keywords/phrases and combinations for searching literature through Google Scholar are as following:

1. “Molecular diagnostics and forensic medicine and healthcare”
2. “Molecular Diagnostics, Forensic Medicine, and Precision Medicine”

Molecular Diagnostics in Healthcare

Modern healthcare has come to integrate molecular diagnostics into its core field, and has assisted in detecting, monitoring and treating diseases through methodologies that exploit high-precision. Personal medicine finds itself developing at an incredible pace with the help of High-Throughput sequencing and next-generation sequencing (NGS) technologies in extremely diverse fields such as cancer research and infectious diseases (Dongare et al., 2025; Mehmood et al., 2025). Similarly, low and middle income countries shall benefit greatly from CRISPR-based-point-of-care systems (Pakdeerat et al. 2024). Computational biology finds itself being integrated with molecular biology as we see Nucleic Acid Amplification tests being streamlined through artificial intelligence (Wei et al., 2024). Detecting pathogens like bacteria and fungi in healthcare environments such as aerosols showcase how we may be able to use these tools for controlling infections (Matys et al., 2024). But, infrastructural gaps, cost barriers and obstacles in regulatory procedures are hindering the integration of molecular diagnostics into clinical systems (Horgan et al., 2024). Similarly, new and previously unused biomarker applications are being used for cardiovascular conditions such as heart failure, blunt cardiac injuries, etc. (Tica & Tica, 2025; Wang et al., 2024; Zhang et al., 2024)

Molecular Diagnostics in Forensic Medicine

Medico-legal and cause-of-death investigations have found improvement as molecular medicine techniques are being picked up by forensic medicine. Postmortem molecular diagnostics are also enabling better forensic casework through DNA extraction methods from degraded or blood samples

(Mohana Rao et al., 2024). Combining genomic profiling with pathological autopsy results in molecular autopsy to improve the diagnosis of conditions like cardiomyopathy and unexplained sudden deaths (Li et al., 2024; Akilzhanova et al., 2025). Forensic cases are also being resolved better through epigenetic and transcriptomic markers in addition to ATA-sequence applications that target degraded DNA (Gerra et al., 2024; Li et al., 2024). “Forensic biomarkers” are also being expanded by focusing studies on non-coding RNAs (Song et al., 2024). Similarly, vibrational spectroscopy and microchip-based DNA capture platforms are able to transcend molecular forensics beyond genetics into the analysis of trace evidence (Fan et al., 2023; Sehgal et al., 2024). Third generation sequencing techniques are also being used to make forensic medicine more reliable and accurate (Hu et al., 2024). Forensic pathology capacity can be strengthened through evidence based, molecularly informed strategies in areas that suffer from low/ limited resources, such as Zambia (Mbawe et al., 2025). Over time, these innovations make it possible to accommodate the transformation of forensic medicine into an integrative field that allows for stronger medico-legal outcome compared to its primary role as morphological sciences.

Cross-Cutting Technologies and Future Directions

Healthcare and forensic applications find themselves being greatly shaped by the culmination of various fields such as artificial intelligence, advanced imaging tools and bioinformatics with classical molecular dynamics, and faster, reliable results are being achieved in forensic practices with the help of AI-driven digital autopsies and the automated interpretation of this generated/ previously available molecular data (Kumar & Vats, 2024; Volonnino et al., 2024). Computational tools are also able to improve the genomic data handling by securing and standardizing the process and enhancing diagnostic pipelines at the same time (Schmidt et al., 2025). Epigenetic profiling, deep cell sequencing and colorimetric nucleic acid detection on membranes are all applications that prove how the same platform can contribute/ target patient care and forensic investigation (Subhashini et al., 2024; Wezi et al., 2025). The social aspects of molecular diagnostics would require in the standardization of ethical oversight, while improving accessibility and improving regulatory frameworks. Forensic science aims for justice and truth while conventional healthcare focuses on personalized medicine and predictive technologies, these two can combine to display a common impact towards shaping human well-being and accountability.

Conceptual diagram: visually links healthcare, forensic medicine, and cross-cutting technologies with their respective innovations

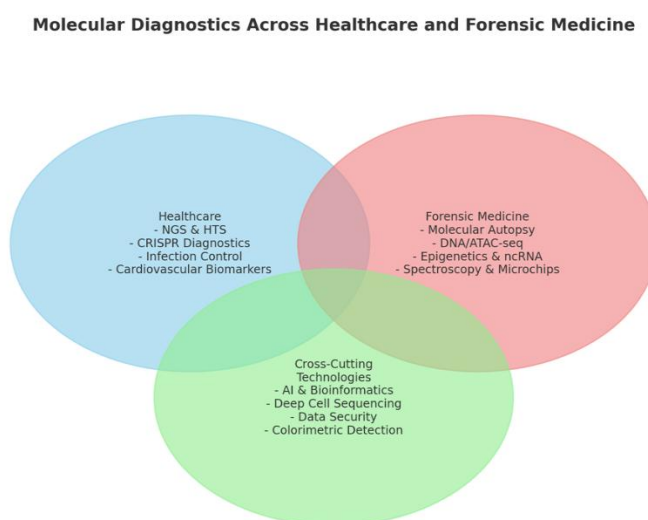


Figure 1: Conceptual diagram

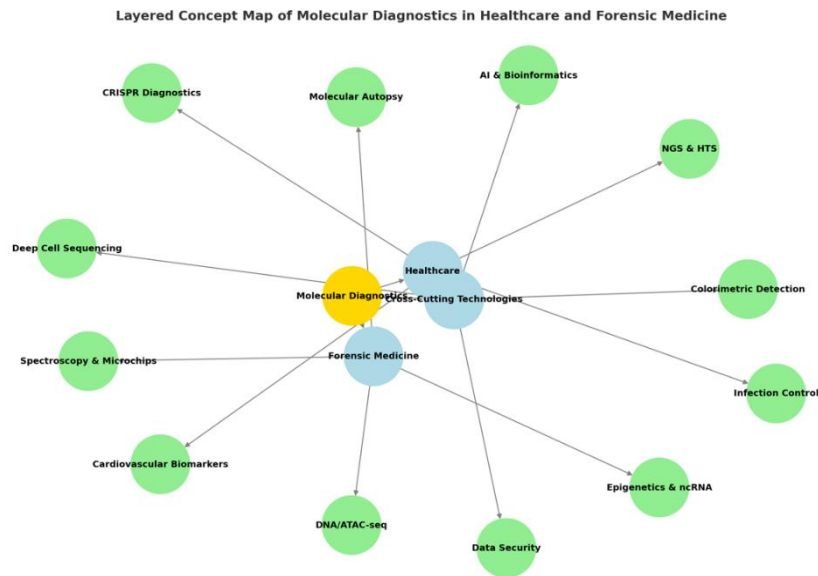


Figure 2: Layered Concept Map

Layered concept map showing Molecular Diagnostics at the center, branching into Healthcare, Forensic Medicine, and Cross-Cutting Technologies, each with their key sub-nodes.

The diagrams generated, were created using Python visualization libraries:

- The first Venn-style conceptual diagram (three overlapping circles) was made with Matplotlib (matplotlib.pyplot + matplotlib.patches).
- The layered concept map (central node branching into sub-nodes) was made with NetworkX (for graph structure) together with Matplotlib (for drawing and layout).

Thus Matplotlib was used for shapes, layout, and plotting and NetworkX was used for graph/network representation (concept map)

Table 1: Molecular Diagnostics and Forensic Medicine References

Sl.No.	Author(s)	Year	Title	Journal / Source	Key Focus / Contribution
1	Matys, J. et al.	2024	“A molecular approach for detecting bacteria and fungi in healthcare environment aerosols: A systematic review”	International Journal of Molecular Sciences 25(8):4154	Systematic review on molecular tools to detect microbial aerosols in healthcare
2	Horgan, D. et al.	2024	“Tackling the implementation gap for the uptake of NGS and advanced molecular diagnostics into healthcare systems”	Heliyon 10(1)	Policy and implementation strategies for NGS and molecular diagnostics
3	Mbawe, Z. et al.	2025	“Forensic Pathology Research Priorities for Zambia: Strengthening Justice and Public Health through Evidence-Based Practice”	International Journal of Research and Scientific Innovation 12(15):655–666	National priorities for forensic pathology and molecular diagnostics in Zambia
4	Choi, N.; Schlücker, S.	2024	“Convergence of surface-enhanced Raman scattering with molecular diagnostics: a perspective on future directions”	ACS Nano 18(8):5998–6007	Perspective on SERS technology in diagnostics
5	Schmidt, R.J. et al.	2025	“Clinical Bioinformatician Body of Knowledge—Clinical Laboratory Regulation and Data Security Core”	Journal of Molecular Diagnostics	Standards for bioinformatics, regulation, and data security
6	Dongare, D.B. et al.	2025	“High-throughput sequencing: A breakthrough in molecular diagnosis for precision medicine”	Functional & Integrative Genomics 25(1):22	Review of NGS in precision diagnostics
7	Țica, O.; Țica, O.	2025	“Molecular Diagnostics in Heart Failure: From Biomarkers to Personalized Medicine”	Diagnostics 15(14):1807	Role of biomarkers in heart failure management

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8	Pakdeerat, S. et al.	2024	"Benchmarking CRISPR-BP34 for point-of-care melioidosis detection in low-income and middle-income countries"	The Lancet Microbe 5(4):e379–e389	Application of CRISPR diagnostics in LMICs
9	Wei, Y. et al.	2024	"Artificial intelligence enhanced digital nucleic acid amplification testing for precision medicine and molecular diagnostics"	arXiv preprint:2407.21080	AI-based digital amplification technologies
10	Qo'chqarov, B.V.	2025	"Postmortem Molecular Diagnostics: Novel Approaches In Forensic Pathology"	Modern Science and Research 4(3):1547–1554	New postmortem molecular forensic methods
11	Alam, Q.; Rafeeq, M.; Umair, M. (eds.)	2025	"Innovations and Implications in Molecular Diagnostics"	CRC Press	Book on innovations and implications in diagnostics
12	Mohana Rao, S.R. et al.	2024	"DNA Extraction from Postmortem Blood: A Pilot Study for Advancing Molecular Diagnostics in Forensic Medicine Casework"	Indian Journal of Forensic Medicine & Toxicology 18(1)	Postmortem DNA extraction study for forensic applications
13	Panga, S.K. et al.	2025	"Recent Advances in Forensic Medicine: An Overview"	Medical Science: Recent Advances and Applications:145	Overview of forensic medicine advances
14	Choi, N.; Schlücker, S.	2024	"Convergence of surface-enhanced Raman scattering with molecular diagnostics: a perspective on future directions"	ACS Nano 18(8):5998–6007	Duplicate entry - SERS in diagnostics
15	Dongare, D.B. et al.	2025	"High-throughput sequencing: A breakthrough in molecular diagnosis for precision medicine"	Functional & Integrative Genomics 25(1):22	Duplicate entry - High throughput sequencing
16	Wang, N. et al.	2024	"Molecular biomarkers of blunt cardiac injury: recent advances and future perspectives"	Expert Review of Molecular Diagnostics 24(11):1023–1031	Biomarkers for blunt cardiac injury
17	Akilzhanova, A. et al.	2025	"Mutational Burden of Genetic Variants in Cardiomyopathy-Associated Genes Provides New Insights for Postmortem Molecular Diagnosis in Kazakhstan"	Journal of Heart and Lung Transplantation 44(4):S222	Genetic burden insights for cardiomyopathy postmortem diagnosis
18	Gerra, M.C.; Dallabona, C.; Cecchi, R.	2024	"Epigenetic analyses in forensic medicine: future and challenges"	International Journal of Legal Medicine 138(3):701–719	Review of epigenetics in forensic medicine
19	Li, M. et al.	2024	"From degraded to deciphered: ATAC-seq's application potential in forensic diagnosis"	International Journal of Legal Medicine 138(4):1273–1285	Application of ATAC-seq in degraded forensic samples
20	Jaies, I. et al.	2024	"Immunological and molecular diagnostic techniques in fish health: present and future prospectus"	Molecular Biology Reports 51(1):551	Molecular diagnostics in fish health
21	Li, Z. et al.	2024	"The grading diagnostic strategy of molecular autopsy combined with pathological autopsy in the forensic diagnosis of cardiomyopathy"	Legal Medicine 68:102380	Grading strategy combining molecular and pathological autopsy
22	Kaushik, R. et al.	2025	"Introduction to Molecular Diagnostics and Viral Diseases"	In Molecular Diagnostics for Viral Diseases: Challenges and Emerging Concepts (Springer Nature Singapore)	Book chapter introducing viral diagnostics
23	Zaib, U. et al.	2025	"Forensic Challenges in Diagnosing Meningococcal Sepsis Postmortem"	International Journal of Pharmacy Research & Technology 15(2):1737–1742	Challenges in diagnosing meningococcal sepsis postmortem
24	Zhang, Y. et al.	2024	"Molecular biomarkers of diffuse axonal injury: recent advances and future perspectives"	Expert Review of Molecular Diagnostics 24(1–2):39–47	Biomarkers for diffuse axonal injury
25	Mehmood, F.; Javed, K.; Riaz, A.	2025	"Advances in molecular diagnostics: from PCR to next-generation sequencing"	Journal of Health, Medical Research and Innovations 3(2):60–76	Advances in PCR and NGS methods
26	Kumar, S.; Vats, S.V.	2024	"A review article on the transformative impact of artificial intelligence-powered autopsy in forensic medicine"	International Journal for Multidisciplinary Research 6(2):1–7	AI applications in forensic autopsy
27	Wei, Y. et al.	2024	"Artificial intelligence enhanced digital nucleic acid amplification testing for precision medicine and molecular diagnostics"	arXiv preprint:2407.21080	Duplicate entry - AI-enhanced nucleic acid amplification
28	Fan, Z. et al.	2025	"The application of vibrational spectroscopy in forensic analysis of biological evidence"	Forensic Science, Medicine and Pathology 21(1):406–416	Vibrational spectroscopy in forensic biology

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29	Abdullah, S.; Mohammed, M.	2024	"Molecular diagnosis using metagenomic technology on wastewater from the Danville Valley in the city of Mosul, Iraq"	Jordan Journal of Applied Science – Natural Science Series 18:12–16	Metagenomics-based wastewater diagnostics
30	Hu, X. et al.	2024	"Research progress and application of the third-generation sequencing technologies in forensic medicine"	Legal Medicine 71:102532	Third-generation sequencing applications in forensic science
31	Aidy, S.T.M. et al.	2024	"Beyond Histology: Genetic and Transcriptomic Insights into the Postmortem Diagnosis of Mechanical Asphyxia"	Pegem Journal of Education and Instruction 14(3):455–460	Genetic and transcriptomic markers for mechanical asphyxia
32	Falletti, J. et al.	2024	"An update on myocarditis in forensic pathology"	Diagnostics 14(7):760	Myocarditis diagnostics in forensic pathology
33	Durango-Manrique, Y.; López-Rubio, A.; Gómez, G.F.	2025	"Molecular differentiation analysis of ten putative species of Fannia (Diptera: Fanniidae) collected in carrion-baited traps from Colombia"	Medical and Veterinary Entomology 39(1):3–13	Molecular differentiation of carrion insects
34	Horgan, D. et al.	2024	"Tackling the implementation gap for the uptake of NGS and advanced molecular diagnostics into healthcare systems"	Heliyon 10(1)	Duplicate entry - implementation of NGS
35	Fragkou, K. et al.	2025	"From Fragile Lives to Forensic Truth: Multimodal Forensic Approaches to Pediatric Homicide and Suspect Death"	Diagnostics 15(11):1383	Pediatric forensic investigation approaches
36	Wezi, K. et al.	2025	"Deep Cell Sequencing: A Next-Generation Tool for Enhanced Diagnostics and Precision Medicine in Africa"	Unspecified	Deep cell sequencing in Africa
37	Subhashini, N. et al.	2024	"Enhancing colorimetric detection of nucleic acids on nitrocellulose membranes: cutting-edge applications in diagnostics and forensics"	Biosensors 14(9):430	Colorimetric nucleic acid detection innovations
38	Mbawe, Z. et al.	2025	"Forensic Pathology Research Priorities for Zambia: Strengthening Justice and Public Health through Evidence-Based Practice"	International Journal of Research and Scientific Innovation 12(15):655–666	Duplicate entry - Zambia priorities
39	Song, B.; Qian, J.; Fu, J.	2024	"Research progress and potential application of microRNA and other non-coding RNAs in forensic medicine"	International Journal of Legal Medicine 138(2):329–350	Review on ncRNAs in forensic medicine
40	Sehgal, S. et al.	2024	"Fabrication of a Microchip for efficient DNA Capture and Release from Human Blood Sample for Forensic Application"	Journal of Punjab Academy of Forensic Medicine & Toxicology 24(1)	Microchip for DNA extraction in forensics
41	Campuzano, O. et al.	2025	"Brugada syndrome in the forensic field: what do we know to date?"	Frontiers in Cardiovascular Medicine 12:1618762	Forensic implications of Brugada syndrome
42	Volonnino, G. et al.	2024	"Artificial intelligence and future perspectives in Forensic Medicine: a systematic review"	Clinica Terapeutica 175(3)	Systematic review of AI in forensic medicine

Advances at the Intersection of Molecular Diagnostics, Forensic Medicine, and Precision Medicine

Molecular diagnostics, forensic medicine and precision medicine have combined to revolutionize healthcare and legal investigations, and are a driving force towards accurate diagnostics, tailored therapies and precise forensic analyses. The more recent literature showcases these similar, interconnected fields advancing significantly, and shows the great potential of molecular and genomic technologies when combined with “artificial intelligence (AI) and multi-omics approaches”.

Molecular Diagnostics: From Biomarkers to Personalized Care

The early detection, prognosis and monitoring of diverse conditions is greatly enabled by molecular diagnostics, as they play an extremely important role in the identification of disease specific biomarkers. Work by Tica and Tica (2025) highlights the importance of molecular profiling to help clinicians in creating tailored interventions to individual patient profiles resulting in improved

outcomes when transitioning from traditional biomarkers to personalized medicinal frameworks when concerning molecular diagnostics in heart failure. AI and molecular testing also synergise together to accelerate diagnostic timelines while ensuring that sensitivity and specificity are improved to ensure betterment of personalized medicines applications, through the integration of AI with digital nucleic acid amplification technologies to improve diagnostic accuracy (Wei et al., 2024). Son et al. (2024) also mentions “mass- spectrometry” based advances in biomarker discovery, proving that innovative analytical techniques shall herald the development of precision based diagnostic tools.

Molecular insights are also leading precision treatments, as Adegunsoye et al. (2024) displays how the pulmonary fibrosis genetic/ genomic fibrosis deal with driving precision treatments. Olorunsogo et al. (2024) also reviewed the critical role of bioinformatics to analyse complex genomic data and highlighting its ability to revolutionize the delivery of personalized healthcare. However, there are still hurdles to be considered as the integration of molecular and genetic technologies within the field of personalized medicine include problems concerning the vast data to be integrated and ethical problems (Nakhod et al., 2024). However, multi-omics approaches continue to see success and promise greater, more comprehensive patient profiling (Molla & Bitew, 2024).

Forensic Medicine: Molecular Insights and Technological Innovation

Panga et al. (2025) revise and summarize the recent advances in forensic sciences and highlight the innovations in technology that have provided improved evidence accuracy and investigative processes.

Forensic sciences see more development in Epigenetic analyses, as Gerra et al. (2024) showcase how epigenetic markers may have the potential to allow novel insights into biological samples and can allow forensic investigators newer tools to aid them in resolving more complex cases with a greater degree of certainty. Similarly, the integration of proteomics and genomics shall improve the forensic identification processes from tissue to bone (Procopio & Bonicelli, 2024). Alketbi (2024) also showcases the importance of innovation in DNA analysis in forensic applications by highlighting newer technologies in DNA profiling, which help to improve accuracy while reducing the processing time simultaneously, which is extremely important for legal processes. AI is being more and more utilized through forensic applications to interpret complex molecular data and will lead to enhanced diagnostic reliability and improved judicial decision making in the future.

Precision Medicine: Tailoring Treatment with Multi-Omics and AI

Precision medicine will cause a generational shift in healthcare and will shift the emphasis towards individualized therapeutic strategies that are guided by molecular diagnostics and genomics. Nori et al. (2025) showcase the immense role AI is capable of playing on healthcare, and how it is important in analysing a large number of molecular datasets of immense volume to inform precision therapies. There is a need of frameworks that will provide for ethical, equitable and safe application of precision diagnostics and treatments, and these regulatory challenges faced by personalized medicine are addressed by Dharani and Kamaraj (2024). Puco et al. (2024) also report on the IMPRESS-Norway initiative that shall integrate precision medicine into public cancer care with hopeful inclusion rates and outcomes. Pitchika et al. (2024) showcase how computational tools can refine diagnostic precision by exploring various AI-assisted personalized diagnostics in periodontology. Robertson et al. (2024) also support the integration of EHR (Electronic Health Record) data with genomic data, showcasing how an integrated database ecosystem would be important in supporting precision medicine. Taherdoost and Ghofrani (2024) showcase how Pharmacogenomics which is a cornerstone of personalized therapy benefits greatly from AI, showing the transformative role AI is able to play to optimize the drug therapy based on genetic profiles of each individual to maximize efficiency and minimize side effects.

Khalighi et al. (2024) also displays research that showcases the applications of AI in neuro-oncology, where brain tumour managements can be significantly improved with the help of precision diagnostics

and treatments. Carini and Seyhan (2024) shed a light on the challenges faced and the future scope of AI in personalized medicine, showing that AI could build trust and interpretability in clinical settings. Mani et al. (2025) show how “the integration of multi-omics data” including “genomics, proteomics” and metabolomics allow for a rich molecular landscape to support personalized medicine. Tuminello et al. (2025) expose that there are racial and socioeconomic disparities affecting the uptake of these molecular diagnostics and call for strategies that may enable groups with limited access of these services to get inclusive access in the future.

Converging Technologies and Future Directions

AI is able to emerge as integrator of technologies across the fields of molecular diagnostics, forensic medicine and precision medicine. Zahra et al. (2024) discuss how AI and personalized medicine exist synergistically and lead to enhanced diagnosis and treatment of diseases while preventing them whenever possible. Chen et al. (2024) also focus on the applications of deep learning on glioblastoma which illustrate how precision medicine may be pivotal in such complicated cases of oncology. However, these multiple methods lead to multiple data types, and their healthy integration remains a necessity. Brancato et al. (2024) showcase the importance of digital biobanks that can combine different forms of data such as clinical, genomic and imaging data to smoothen research and clinical application. Jurisica (2024) expects for more explainable AI models in the future, whereas (Dus et al. 2024) advocate for advanced molecular imaging techniques more, and these all approaches and advancements will propagate the fields forward and enhance clinical care and forensic investigations.

Observation

The recent trends and literature showcase that rapid enhancements are occurring at the crossways of molecular diagnostic, forensic medicine and precision medicine. Molecular technologies and AI together will lead to improved and unseen accuracy in diagnostics and personalized treatment. These tools also help forensic medicine in providing precise evidence, analysis and the integration of multi-omics approaches and AI-enhanced analytics enhance the evolution of precision medicine. However, challenges in the fields of data equity, integration and regulation remain, and the complete potential of these fields can only be fulfilled with the help of continued interdisciplinary collaboration and technological innovations.

Table 2: Precision Medicine, Molecular Diagnostics & Forensic Science References

Sl.No.	Authors	Title	Journal / Source	Year	Key Theme / Focus
1	Panga, Surya Kiran, et al.	“Recent Advances in Forensic Medicine: An Overview”	Medical Science: Recent Advances and Applications	2025	Overview of forensic medicine advancements
2	Gerra, Maria Carla, Cristina Dallabona, and Rossana Cecchi	“Epigenetic analyses in forensic medicine: future and challenges”	International Journal of Legal Medicine 138(3)	2024	Epigenetics applications in forensic medicine
3	Țica, Ovidiu, and Otilia Țica	“Molecular Diagnostics in Heart Failure: From Biomarkers to Personalized Medicine”	Diagnostics 15(14):1807	2025	Heart failure biomarkers and personalized medicine
4	Wei, Yuanyuan, et al.	“Artificial intelligence enhanced digital nucleic acid amplification testing for precision medicine and molecular diagnostics”	arXiv preprint arXiv:2407.21080	2024	AI in nucleic acid amplification
5	Son, Ahrum, et al.	“Mass spectrometry advancements and applications for biomarker discovery, diagnostic innovations, and personalized medicine”	International Journal of Molecular Sciences 25(18):9880	2024	Mass spectrometry in biomarker discovery

6	Procopio, Noemi, and Andrea Bonicelli	"From flesh to bones: Multi-omics approaches in forensic science"	Proteomics 24(12-13):2200335	2024	Multi-omics in forensic science
7	Nori, Lakshmi Prasanthi, et al.	"Revolutionizing Healthcare: The Impact of AI on Precision Medicine"	International Journal of Pharmaceutical Investigation 15(2)	2025	AI in precision medicine
8	Dharani, S., and R. Kamaraj	"A review of the regulatory challenges of personalized medicine"	Cureus 16(8)	2024	Regulatory challenges in personalized medicine
9	Puco, Katarina, et al.	"IMPRESS-Norway: improving public cancer care by implementing precision medicine in Norway; inclusion rates and preliminary results"	Acta Oncologica 63	2024	Precision medicine implementation in Norway
10	Pitchika, Vinay, Martha Büttner, and Falk Schwendicke	"Artificial intelligence and personalized diagnostics in periodontology: A narrative review"	Periodontology 2000 95(1):220-231	2024	AI and personalized diagnostics in dentistry
11	Robertson, Alan J., et al	"It is in our DNA: Bringing electronic health records and genomic data together for precision medicine"	JMIR Bioinformatics and Biotechnology 5:e55632	2024	Integration of genomics with EHRs
12	Taherdoost, Hamed, and Alireza Ghofrani	"AI's role in revolutionizing personalized medicine by reshaping pharmacogenomics and drug therapy"	Intelligent Pharmacy 2(5):643-650	2024	AI in pharmacogenomics
13	Adegunsoye, Ayodeji, et al.	"Genetics and genomics of pulmonary fibrosis: charting the molecular landscape and shaping precision medicine"	American Journal of Respiratory and Critical Care Medicine 210(4):401-423	2024	Genomics of pulmonary fibrosis
14	Olorunsogo, Tolulope O., et al.	"Bioinformatics and personalized medicine in the US: A comprehensive review"	World Journal of Advanced Research and Reviews 21(1):335-351	2024	Bioinformatics in US personalized medicine
15	Nakhod, Valeriya, et al.	"Advances in molecular and genetic technologies and the problems related to their application in personalized medicine"	Journal of Personalized Medicine 14(6):555	2024	Challenges in molecular/genetic tech
16	Molla, Getnet, and Molalegne Bitew	"Revolutionizing personalized medicine: synergy with multi-omics data generation, main hurdles, and future perspectives"	Biomedicines 12(12):2750	2024	Multi-omics and future of personalized medicine
17	Evans, William, et al.	"Precision medicine—are we there yet? A narrative review of precision medicine's applicability in primary care"	Journal of Personalized Medicine 14(4):418	2024	Precision medicine in primary care
18	Alketbi, Salem Khalifa	"Emerging technologies in forensic DNA analysis"	Perspectives in Legal and Forensic Sciences 1(1)	2024	Emerging forensic DNA technologies
19	Khalighi, Sirvan, et al.	"Artificial intelligence in neuro-oncology: advances and challenges in brain tumor diagnosis, prognosis, and precision treatment"	NPJ Precision Oncology 8(1):80	2024	AI in neuro-oncology

20	Carini, Claudio, and Attila A. Seyhan	“Tribulations and future opportunities for artificial intelligence in precision medicine”	Journal of Translational Medicine 22(1):411	2024	AI in precision medicine opportunities
21	Kothinti, Rishi Reddy	“Artificial intelligence in healthcare: Revolutionizing precision medicine, predictive analytics, and ethical considerations in autonomous diagnostics”	World Journal of Advanced Research and Reviews 19(3):3395-3406	2024	AI in healthcare & ethics
22	De Wachter, Matthias, et al.	“From diagnosis to treatment in genetic epilepsies: Implementation of precision medicine in real-world clinical practice”	European Journal of Paediatric Neurology 48:46-60	2024	Precision medicine in genetic epilepsies
23	David, Emanuele, et al.	“Thyroid nodule characterization: Overview and state of the art of diagnosis with recent developments, from imaging to molecular diagnosis and artificial intelligence”	Biomedicines 12(8):1676	2024	Thyroid nodule diagnosis with AI/molecular tools
24	Jurisica, I.	“Explainable biology for improved therapies in precision medicine: AI is not enough”	Best Practice & Research Clinical Rheumatology 38(4):102006	2024	Explainable AI in biology
25	Duo, Yanhong, Lei Han, et al.	“Aggregation-induced emission luminogen: role in biopsy for precision medicine”	Chemical Reviews 124(20):11242-11347	2024	AIE luminogens in biopsy
26	Mani, Srinivasan, Seema R. Lalani, and Mohan Pammi	“Genomics and multiomics in the age of precision medicine”	Pediatric Research	2025	Genomics and multiomics in pediatrics
27	Brancato, Valentina, et al.	“Standardizing digital biobanks: integrating imaging, genomic, and clinical data for precision medicine”	Journal of Translational Medicine 22(1):136	2024	Digital biobanks for precision medicine
28	Zahra, Mohammad Abu, et al.	“The synergy of artificial intelligence and personalized medicine for the enhanced diagnosis, treatment, and prevention of disease”	Drug Metabolism and Personalized Therapy 39(2):47-58	2024	AI-personalized medicine synergy
29	Chen, Pengyu, Ping Wang, and Bo Gao	“The application value of deep learning in the background of precision medicine in glioblastoma”	Science Progress 107(1):00368504231223353	2024	Deep learning in glioblastoma precision medicine
30	Tuminello, Stephanie, et al.	“Racial and socioeconomic disparities in non-small cell lung cancer molecular diagnostics uptake”	JNCI: Journal of the National Cancer Institute 117(1):112-119	2025	Disparities in lung cancer molecular diagnostics

Research Flow and Description:

1. Molecular Diagnostics Development: These improve the speed and sensitivity of molecular assays and incorporate AI for enhanced data analysis
2. Multi-Omics Integration: These combine genomics, proteomics, epigenetics data and develop comprehensive molecular profiles
3. AI & Bioinformatics Applications: Includes AI-driven data interpretation (clinical & forensic) and automated diagnostics and forensic evidence analysis
4. Digital Biobanks & Data Standardization: Involves integration of clinical, imaging and molecular data along with the standardization of data formats and interoperability.

5. Precision Medicine Implementation: These enable personalized treatment for patients based on molecular profiles and address real-world clinical challenges.
6. Forensic Medicine Enhancements: Application of multi-omics and AI to forensic casework and improvement biological evidence accuracy and reliability.
7. Regulatory & Ethical Frameworks: These help in the development of guidelines for AI and molecular diagnostics use while ensuring ethical, equitable access.
8. Addressing Disparities: Building research strategies for inclusive access and implementation of global democratization of technologies.

Rapid Review of AI in Molecular Diagnostics and Forensic Medicine

1. Overview

Artificial Intelligence (AI) is increasingly integrated into molecular diagnostics and forensic medicine to enhance accuracy, speed, and predictive power. AI applications range from pattern recognition in genomic data, digital pathology, multi-omics analysis, to automated forensic investigations. These applications support precision medicine and improve postmortem analysis in forensic casework.

The following duplications (07) were removed before conducting rapid review:

1. “Choi, Namhyun, and Sebastian Schlücker (2024)”;
2. “Dongare, Dipali Barku, Shaik Shireen Nishad, Sakshi Y. Mastoli, Shubhini A. Saraf, Nidhi Srivastava, and Abhishek Dey (2025)”;
3. “Horgan, Denis, Marc Van den Bulcke, Umberto Malapelle, Giancarlo Troncone, Nicola Normanno, Ettore D. Capoluongo, Arsela Prelaj et al. (2024)”;
4. “Mbawe, Zulu, Arthur Chisanga, Musimuko Ellison, Hadriana Hanafie, Tembo Frenshus, Hasting Zulu, Kelvin Adutwum-Ofosu, Nnoli Anazodo Martin, and Munsaka Mweetwa Sody (2025)”;
5. “Panga, Surya Kiran, D. Balaji, Harshita Dubey, Shivam Dwivedi, Abhishek Yadav, Gunvanti B. Rathod, Gyanendra Singh et al. (2025)”;
6. “Țica, Ovidiu, and Otilia Țica (2025); Wei, Yuanyuan, Xianxian Liu, Changran Xu, Guoxun Zhang, Wu Yuan, Ho-Pui Ho, and Mingkun Xu (2024)”;
7. “Wei, Yuanyuan, Xianxian Liu, Changran Xu, Guoxun Zhang, Wu Yuan, Ho-Pui Ho, and Mingkun Xu. (2024)”.

Keywords/phrases and combinations for searching literature through Google Scholar are as following:

1. “Molecular diagnostics and Forensic medicine and Healthcare”
2. “Molecular Diagnostics, Forensic Medicine, and Precision Medicine”

PRISMA Flow Diagram for Molecular Diagnostics and Forensic Medicine Review

I. Identification

Records identified through database searching: 72

Records after duplicates removed: 63

II.Screening

Records screened (title & abstract): 63

Records excluded (irrelevant)/duplicate: 09

III. Eligibility

Full-text/Abstract articles assessed for eligibility: 63

Full-text/Abstract articles excluded with reasons: 0

IV.Included

Studies included in qualitative synthesis: 63

Studies included in quantitative synthesis (meta-analysis, if any): N/A

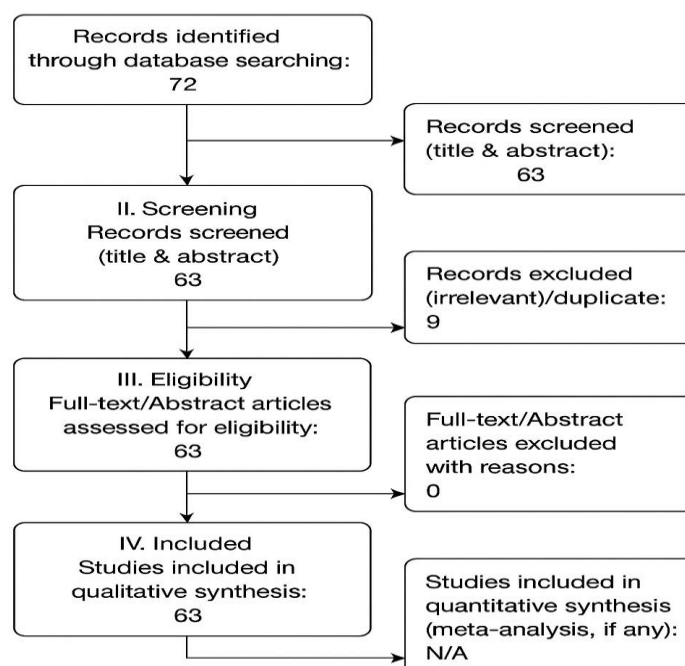


Figure 3: PRISMA Flow Diagram

By using SmartArt, the PRISMA Flow Chart has been prepared as it is flexible to create by adding the PRISMA stages, editing the text inside each block and insert arrows manually.

2. AI in Molecular Diagnostics

Sl. No.	Reference	AI Application	Key Insights
1.	Carini & Seyhan, 2024 (9)	Precision medicine	AI facilitates integration of large-scale genomic and clinical data for disease prediction and treatment planning.
2.	Chen et al., 2024 (10)	Deep learning in glioblastoma	AI-based deep learning algorithms improve tumor classification and prognosis accuracy.
3.	David et al., 2024 (12)	Imaging & AI	AI assists in thyroid nodule characterization by combining imaging with molecular data.
4.	Khalighi et al., 2024 (30)	Neuro-oncology	AI enhances diagnosis, prognosis, and treatment strategies for brain tumors using complex datasets.
5.	Kothinti, 2024 (31)	Healthcare analytics	AI predicts disease progression, supports decision-making, and addresses ethical concerns in autonomous diagnostics.
6.	Nori et al., 2025 (42)	Precision medicine	AI-driven data analytics accelerates personalized treatment and drug selection.
7.	Pitchika et al., 2024 (46)	Dental diagnostics	AI improves precision in periodontology by integrating personalized diagnostics.
8.	Son et al., 2024 (53)	Mass spectrometry	AI algorithms enhance biomarker discovery and molecular diagnostic accuracy.
9.	Taherdoost & Ghofrani, 2024 (56)	Pharmacogenomics	AI reshapes drug therapy by analyzing patient-specific molecular data.
10.	Wei et al., 2024 (61, 62)	Digital nucleic acid testing	AI enhances amplification testing for precision molecular diagnostics.
11.	Zahra et al., 2024 (64)	Personalized medicine	AI synergizes with molecular diagnostics to optimize disease prevention, diagnosis, and treatment.

Molecular diagnostic results find improvements in their accuracy, speed and interpretability, as well as enabling of personalized therapy decisions along with integration of “multi-omics data”. Deep learning, “machine learning algorithms” and “predictive modelling” are some of the common tools used.

3. AI in Forensic Medicine

Sl. No.	Reference	AI Application	Key Insights
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1.	Kumar & Vats, 2024 (32)	Autopsy	Case resolution improved as autopsy powered by AI improves detection of subtle forensic markers
2.	Campuzano et al., 2025 (8)	Cardiac forensic genetics	Postmortem identification of inherited cardiac disorders is supported.
3.	Fragkou et al., 2025 (21)	Pediatric homicide analysis	Integration of forensic, clinical and genetic data through multimodal AI for accurate cause-of-death determination.
4.	Volonnino et al., 2024 (59)	Systematic review	DNA and injury pattern analysis and other predictive modelling of forensic casework helped by AI.
5.	Qoâ€™chqarov, 2025 (49)	Postmortem molecular diagnostics	Improved detection of biochemical and molecular markers due to AI based methods
6.	Li et al., 2024 (33, 34)	Molecular autopsy	AI assists in analyzing genomic and pathological data for cardiomyopathy-related deaths.
7.	Wei et al., 2024 (61, 62)	DNA testing	AI-based algorithms enhance forensic DNA amplification, increasing sensitivity and reducing errors.

AI is able to automate DNA and molecular analyses, and therefore supports forensic investigations. It can also integrate multi-source data, detect subtle patterns in postmortem studies and improve the accuracy of cause-of-death determinations.

4. Key Themes Across AI Applications

1. **Data Integration:** AI integrates genomics, proteomics, imaging, and clinical data, making comprehensive diagnostics easier
2. **Predictive Analytics:** AI can predict disease outcomes and forensic patterns and enables precision interventions.
3. **Automation & Efficiency:** AI is capable of reducing manual processing time in molecular testing and autopsy workflows.
4. **Forensic Accuracy:** AI helps to improve the detection of subtle molecular changes postmortem, therefore enhances case resolution.
5. **Ethical & Regulatory Considerations:** AI adoption must be able to navigate privacy, bias, and ethical frameworks (Dharani & Kamaraj, 2024; Kothinti, 2024).

5. Findings

- AI is transformative in molecular diagnostics, offering rapid, accurate, and multi-omics-informed analyses for precision medicine.
- In forensic medicine, AI enhances postmortem molecular testing, integrates complex datasets, and improves diagnostic confidence.
- Challenges remain in standardization, regulatory compliance, ethical governance, and data interpretation, which require coordinated research and policy development.

Conclusion and Future Research Directions

The integration of molecular diagnostics with precision medicine and forensic applications through advanced technologies including multi-omics, artificial intelligence and management of digital data. Developing more sensitive and rapid molecular assays capable of leveraging AI-driven analysis for the improvement of diagnostic accuracy and personalization of treatment strategies for complicated disease such as cancer, neural issues and cardiovascular conditions should be a key goal. Research in forensic medicine is branching into epigenetics and multi-omics approaches to help in improving the reliability and scale of biological evidence so that more precise identification of individuals and case reconstruction can be done. AI tools are also being integrated with molecular data to advance forensic investigations through the processes of data-interpretation refinement and automation.

Future efforts should aim towards standardization of data integration from multi-omics approaches and clinical sources into digital biobanks so that the application of personalized medicine in real world clinical and forensic settings can be improved. Addressing disparities in access to molecular diagnostics and precision treatments remains critical, pushing researchers to explore inclusive strategies that democratize these innovations globally. Overall, multidisciplinary collaboration combining bioinformatics, AI, molecular biology, and clinical sciences will drive the next generation of personalized diagnostics and forensic methodologies.

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